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Procedia Engineering 5 (2010) 1438–1441

Procedia Engineering

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Proc. Eurosensors XXIV, September 5-8, 2010, Linz, Austria

Simple inductively coupled resonance sensor for ECG and heart rate monitoring

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Abstract

An inductively coupled passive resonance sensor for the measurement of bioelectric signals is presented. The sensor element is extremely simple containing only a few passive components and a pair of electrodes. It is affordable to manufacture and since it is a totally passive device, it is suitable for wearable and body sensor applications where a near field reading technique can be used. The sensor can be attached to the skin like a sticking plaster and could be even implanted if properly miniaturized. Design and use of the measurement system for ECG and heart rate measurements in wearable applications is presented and evaluated.

Keywords: Inductive coupling; passive resonance sensor; bioelectric signal; ECG; heart rate

1. Introduction

Electrocardiogram (ECG) and heart rate (HR) are traditionally measured with electrodes placed on the skin of the patient and connected with cables to an amplifier with high input impedance and sufficient common mode rejection ratio (CMRR). The measurement system demands somewhat complex electronics and a power source, like a battery. These both add to the cost and increase the size of the device. This can be a problem especially in wearable or implantable applications.

In an alternative method [1] to measure bioelectric signals the instrumentation is highly simplified when compared with the existing methods with batteries [eg. 2, 3] and even without batteries [4, 5]. The sensor is passive and there is no need to use an external power supply. In this paper, we present the measurement method which is based on an LC resonance sensor inductively coupled to a reader device able to interact with the sensor. A hand-held impedance measurement device includes a method for compensating the errors in the measured values related to the changes of the reading distance. The sensor is lightweight, affordable to manufacture and can possibly be made implantable.

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doi:10.1016/j.proeng.2010.09.386

2. Measurement system

The measurement device consists of two units, a reader and a sensor, that are coupled together through an inductive link established between the coils in both units functioning as antennas. A schematic figure of a simplified reader device coil and sensor unit is shown in Fig. 1. The resonance sensor connected with the reader circuitry over an inductive link can be reduced to a single circuit element with impedance X_2. A good indicator of the coupling efficiency between two coils is the coupling coefficient $k = M(L_1L_2)^{-1/2}$ where M is the mutual inductance between the coils with inductances L_1 and L_2. Coupling coefficient depends on the size, distance, the number of turns and geometry of the coupled coils. All variations in the value of the impedance will be reflected in the reader unit signal and can thus be measured. This interrogation technique is well known from various RFID systems. However, in our system the resonance tag is totally passive.

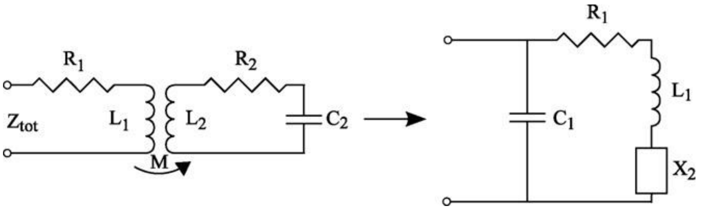
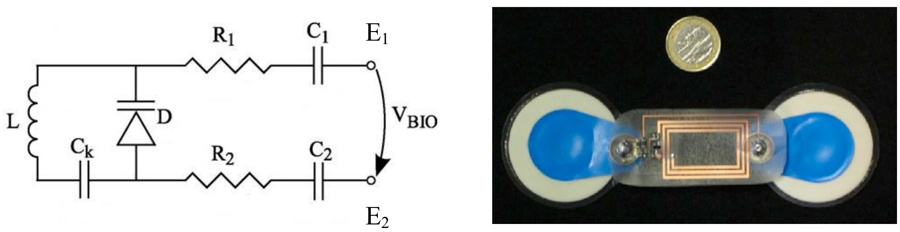


Fig. 1. Schematic figure of the inductively coupled reader coil and resonance sensor, and the sensor part reduced to impedance X_2.

2.1. Resonance sensor

The sensor consists of an LC resonant circuit, capacitance diode and a pair of electrodes (Fig. 1a). The bioelectric voltage sensed by the electrodes modulates the junction capacitance of the varactor diode, and thus also the resonant frequency which is measured over an inductive link as a change in the reflected impedance. The diode operates with a zero bias voltage. The RC high-pass filters (f_{3dB}= 0.16 Hz) cut the half-cell DC-potential of the electrodes and its low-frequency drift. An example of the resonance sensor prototype is shown in Fig. 2b. A planar coil is made on a flexible printed circuit board on which also the components are soldered. Two wet gel Ag/AgCl electrodes (Ambu, Blue Sensor R) are fixed to the board with poppers.



a. b.

Fig. 2. a) Diagram of a sensor based on a single capacitance diode and a pair of electrodes (E_1, E_2) coupled to the resonance circuit via a RC high-pass filter section. V_{BIO} is the bioelectric signal coupled to the electrodes. b) A prototype of the resonance sensor fabricated on a flexible circuit board. The electrodes are fixed with poppers on the board.

2.2. Reader unit

The reader unit is a robust, easy-to-use instrument capable of measuring resonance sensors with a wide range of operating frequencies. In this application, the reader is optimized for the frequency range of 25-50 MHz. The measurement is based on the impedance spectrum measurement using the back-scattered signal from the sensor. For the reader unit, an impedance analyzer-like approach combined with PC post processing has been adopted. In this approach, a small portable measurement instrument (Fig. 3) sweeps over the specific frequency range and measures the phase and/or magnitude response of the resonance sensor by using a planar coil made on a printed circuit board. The post-processing software is then used to calculate the resonance frequency and remove the motion-induced frequency changes. The motion of the reader coil with respect to the resonance sensor coil is compensated with a special algorithm based on measured phase data. A detailed description of the reader unit and the compensation method can be found in [6].

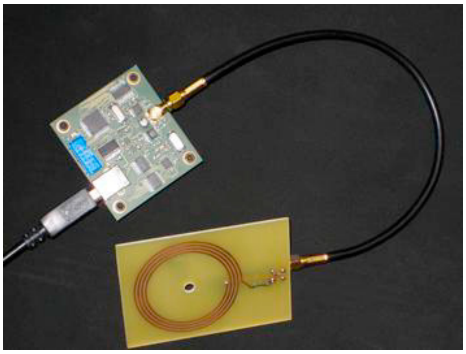


Fig. 3. A small impedance measurement device and planar spiral coil for reading the resonance sensor. The measurement device is further connected to the USB port of PC for data post-processing and analysis.

2.3. Measurement setup

The sensor and reader device were tested by recording ECG signal from test persons. The resonance device with electrodes was attached to the chest of a test person below the left pectoral muscle. The electrodes were oriented along the mean electrical axis of the heart (the sum of all electrical vectors) in order to maximize the signal amplitude. The reader coil was then moved over the resonance sensor by hand and kept at a 10-20 mm distance from it. During the test, the inter-electrode distance was varied from 10 cm to 30 cm by changing the location of the electrodes on the chest but maintaining the orientation along the axis of the heart.

3. Results and discussion

Fig. 4 shows a typical ECG signal recorded with the resonance sensor system using 100 Hz sampling rate. Some noise can be seen in the unfiltered signal (Fig. 4a) but the QRS-complexes and T-waves are easily recognizable. The origin of the noise is the motion of the electrodes and reading coil, and perhaps also the capacitance diode used. The low S/N-ratio evidently prevents the diagnostic use of the record. However, the clearly distinguishable R-peaks can be used to calculate the heart rate. The result of the changes in the inter-electrode distance d can be seen in Fig. 4b. The signals for 10 cm, 20 cm and 30 cm distances are filtered with a 2nd order 40 Hz low-pass filter. Also possible trends have been removed. The change of the electrode distance affects the amplitude of the ECG signal. However, it also modifies the lead field in the thorax and results in the change of the sensitivity distribution and hence the signal features. For the small inter-electrode distance (d = 10 cm) the amplitude is smaller than for the longer distances. It is interesting that for the 20 cm distance the signal has higher amplitude than for the 30 cm distance, and the T-wave is not visible. Anyhow, it is important that when using a short electrode distance the system should be designed carefully to maintain a good S/N-ratio. However, for distances less than 10 cm the signal quality is a challenge.

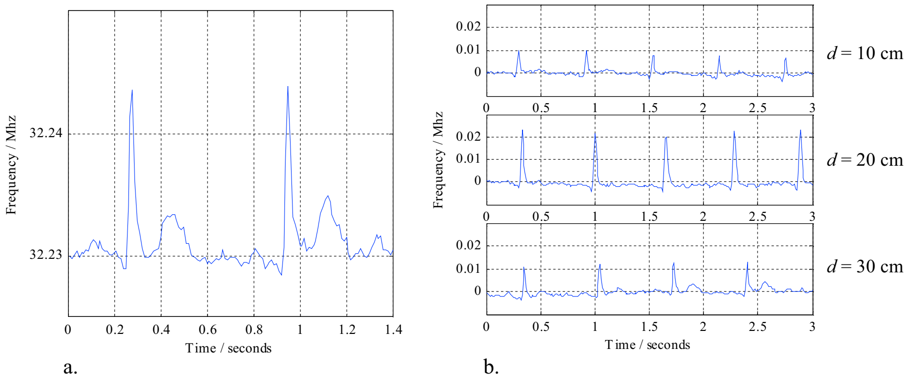


Fig. 4. Unfiltered ECG signal (a). Comparison of ECG signals with three different inter-electrode distances of the resonance sensor (b).

4. Conclusions

A simple, passive wireless resonance sensor and reader based on an inductive interrogation method for measuring bioelectric signals have been presented. The bioelectric voltage sensed by the electrodes modulates the junction capacitance of the capacitance diode and the resonant frequency which is measured over an inductive link as a change in the reflected impedance. The reader device includes a compensation method for changes in the coupling coefficient, which improves the usability of the system. The sensor can be attached to the skin like a sticking plaster and could be even implanted if properly miniaturized. The quality of the measured signals shows that the method has potential for a new kind of measurement interface in wearable and body sensor applications where a near field reading technique can be used.

References

[1] Riistama J, Aittokallio E, Verho J, Lekkala J, Totally passive wireless biopotential measurement sensor by utilizing inductively coupled resonance circuits. Sensors and Actuators A 2010;**157**:313–321.

[2] Mohseni P, Najafi K, Wireless multichannel biopotential recording using and integrated fm telemetry circuit. Proceedings of the 26th Annual International Conference of the IEEE EMBS, San Francisco, USA, September 1–5, 2004.

[3] Mohseni P, Najafi K, A 1.48-mw low-phase-noise analog frequency modulator for wireless biotelemetry. IEEE Transactions on Biomedical Engineering 2005;**52**(5):938–943.

[4] Riistama J, Väisänen J, Heinisuo S, Hyttinen J, Lekkala J, Introducing a wireless, passive and implantable device to measure ECG. In: 3rd European Medical and Biological Engineering Conference, Prague, Czech Republic, November 20–25, 2005.

[5] Riistama J et al., Wireless and inductively powered implant for measuring electrocardiogram. Journal of Medical and Biological Engineering and Computing 2007;**45**:1163–1174.

[6] Salpavaara T, Verho J, Kumpulainen P, Lekkala J, Wireless interrogation techniques for sensors utilizing inductively coupled resonance circuits. Eurosensors XXIV Conference, Linz, Austria, 2010 (to be published).